Status of the JWST Optical Telescope Element

Charlie Atkinson, Scott Texter
Northrop Grumman

And

Ritva Keski-Kuha, Lee Feinberg
Goddard Space Flight Center

ABSTRACT

Significant progress has been made in the development of the Optical Telescope Element (OTE) for the James Webb Space Telescope (JWST) Observatory. All of the mirror assemblies are complete and delivered. The composite Primary Mirror Backplane Support Structure (PMBSS) has completed assembly and in Static Load testing. All the deployment mechanisms have completed their qualification programs. This paper will discuss the current status of all the OTE components and the plan forward to completion.

Keywords: JWST, space-based, observatory, infrared

INTRODUCTION

NASA's James Webb Space Telescope (JWST) will provide new discoveries in astronomy following its launch in 2018. The JWST Observatory is comprised of the Optical Telescope Element (OTE), the Integrated Science Instrument Module (ISIM), the Spacecraft and the Sunshield (see Figure 1). This paper presents the status of the OTE development. Having successfully completed its Critical Design Review in 2009, the OTE has been in production ever since with many hardware assemblies completed and ready for integration. Figure 2 provides an exploded view of the OTE and defines the OTE Subsystems. The status of each subsystem will be discussed in detail.

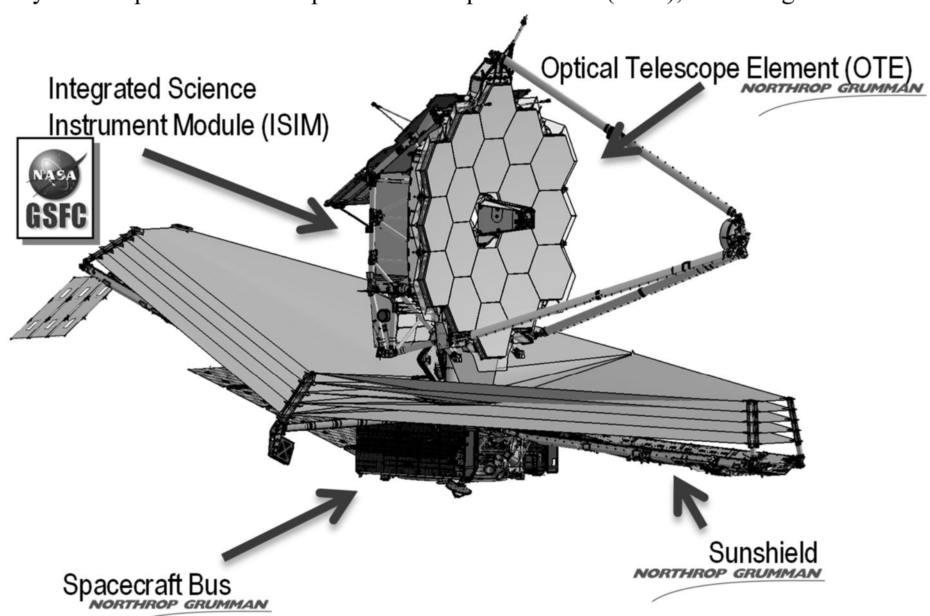

Figure 1: JWST Architecture

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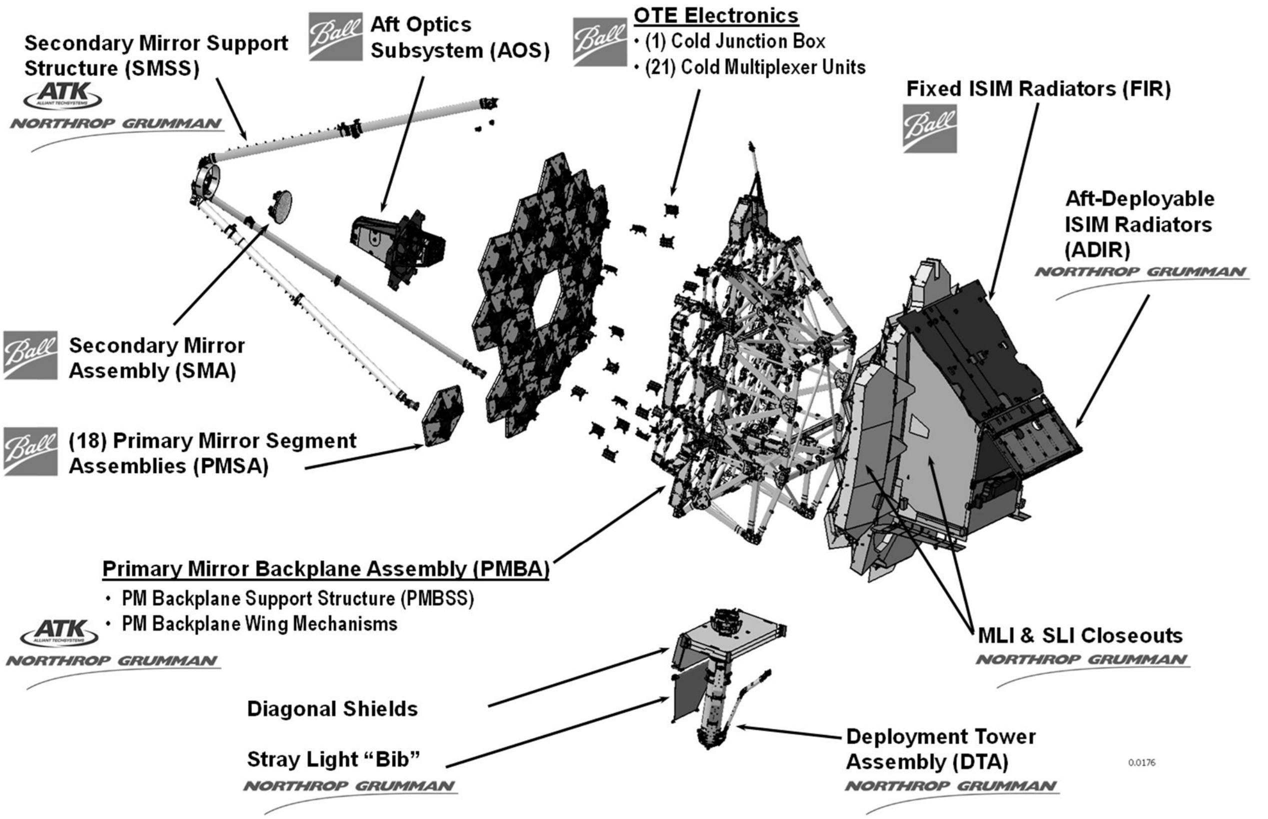

Figure 2: JWST OTE Subsystems

1. Primary Mirror Segment Assemblies and Secondary Mirror Assembly

All 18 Primary Mirror Segment Assemblies (PMSAs) have been fabricated, polished, coated, assembled, and tested. Some minor rework of their actuators was completed at the end of 2013 to improve their life. They are all in hermetically sealed containers, ready for installation. Figure 3 shows a photo of the PMSA shipping containers. Like the PMSAs, the Secondary Mirror Assembly (SMA) has completed fabrication, polishing, coating, assembly, and testing. It too has completed some minor rework of its actuators and is in a hermetically sealed container, ready for installation. As was reported in 2012[1], the optical performance of all the mirrors surpasses requirements.

Figure 3: 18 PMSA shipping containers

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2. Aft Optics Subsystem

The Aft Optics Subsystem (AOS) is the optical heart of the Telescope. It contains the third powered optic in the optical train, the Tertiary Mirror (TM), which is fixed in its location. It also contains the Fine Steering Mirror (FSM). The FSM is located near the exit pupil and provides the steering portion of the inner pointing control system of the nested pointing control system for JWST. It also contains stray light baffles and thermal radiators. The AOS is now completely assembled and has completed all acceptance testing. What remains is some testing to characterize the optical metrology that will be used in final performance characterization of the OTE plus ISIM. Figure 4 depicts the completed AOS.

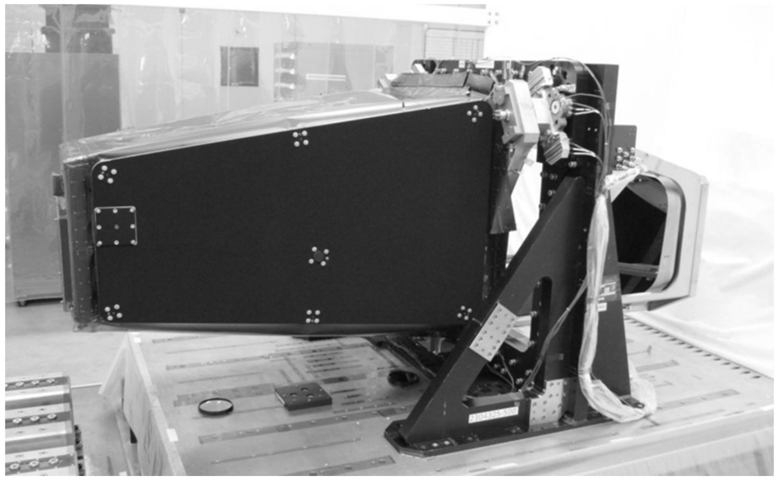

Figure 4: Completed Aft Optics Assembly

3. Primary Mirror Backplane Support System

The Primary Mirror Backplane Support System (PMBSS) is the structure that supports all of the OTE components and the ISIM. Comprised of the main structure, plus the two wings, it is constructed of optimized carbon fiber and a toughened Cyanate resin. The PMBSS contains invar fittings for each of the 18 PMSAs, the ISIM, the AOS, the Secondary Mirror Support System and all the thermal control and stray light control hardware on the telescope. The PMBSS contains over 10,000 adhesive bonds using an adhesive that was selected for its capability to perform at cryogenic temperatures.

The PMBSS is completely assembled, and has completed cryogenic thermal cycling. Post thermal-cycle ultrasonic inspection revealed no anomalies, confirming the workmanship of the PMBSS. It is currently undergoing static load testing. Installation of the PMBSS into the static test frame is captured in Figure 5. The wings, awaiting their static load testing, are captured in Figure 6.

Figure 5: PMBSS loading into Static Test Fixture

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Figure 6: Wings, depicted in final assembly

As part of the cryogenic cycling, measurements were made of the critical AOS to ISIM interface alignment. Because the AOS and ISIM are fixed, ensuring their alignment is maintained during the transition from room temperature to operating temperature, a change of roughly 250K, is extremely important. A set of 26 distance measuring interferometers were used to establish a stable reference and measure the change in relative displacements. Figure 7 depicts the PMBSS in the thermal shroud at the Xray Cryogenic Facility at Marshall Space Flight Center, along with the 26 metrology beams used to measure the change in displacements as the PMBSS is thermally cycled. The inset table shows the as-measured displacements compared to the required cooldown displacements and the very large margins in performance achieved.

	V1 (um)	V2 (um)	V3 (um)	RV1 (urad)	RV2 (urad)	RV3 (urad)
Requirement	+/-1500	+/-500	+/-500	+/-200	+/-300	+/-300
Measured	228	- 26	- 133	0.6	19	- 12

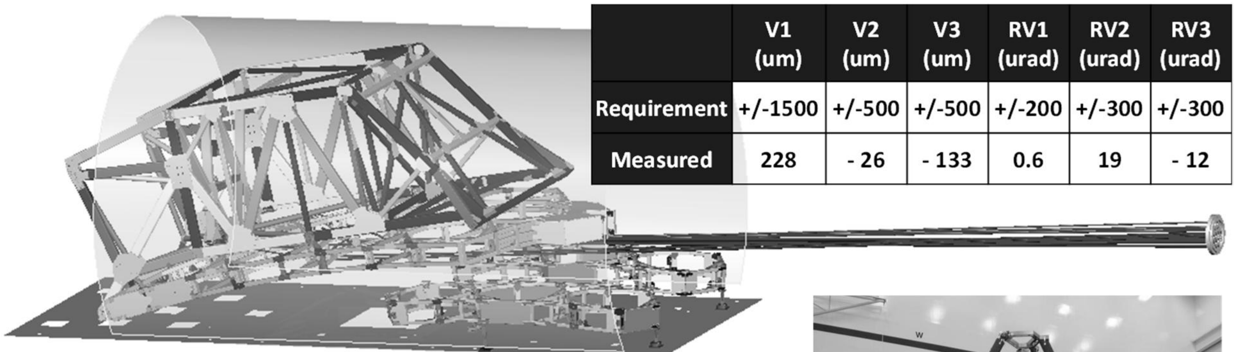

Figure 7: PMBSS cooldown metrology and results

4. Secondary Mirror Support System

The Secondary Mirror Support System (SMSS) is a deployable set of booms that hold the SMA in position after launch. Two long struts, the dual struts, are 24 feet long. They are hinged at the base and fixed to the Secondary Mirror Mount. The single strut is hinged at the top, middle, and bottom to form a 4-bar linkage.

The SMSS struts are made of composite, and have completed assembly, cryogenic cycling, and load testing. The SMSS mechanisms that are used to deploy and latch the SMSS have completed their qualification testing, and the flight mechanisms are built and in testing at the mechanism level. The process to align and assemble the SMSS has already been demonstrated on the high-fidelity Pathfinder, depicted in Figure 8. Assembly of the flight SMSS is due to start around the time of the SPIE Conference.

Figure 8: Pathfinder SMSS

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The mechanisms used to deploy and latch the two wings, which contain 3 PMSAs each, have also completed all their qualification testing. The flight mechanisms are currently in fabrication and assembly.

5. Deployable Tower Assembly

The Deployable Tower Assembly (DTA) deployment mechanism has completed its qualification testing. The flight mechanism has been built and has completed all of its acceptance testing, including vibration testing and deployment testing. The next steps are to integrate the inner and outer tubes, plus cable trays, and perform assembly-level deployment testing at operational temperatures. Figure 9 contains photographs of the inner and outer DTA tubes on the left, and the DTA mechanism in its vibration test fixture on the right.

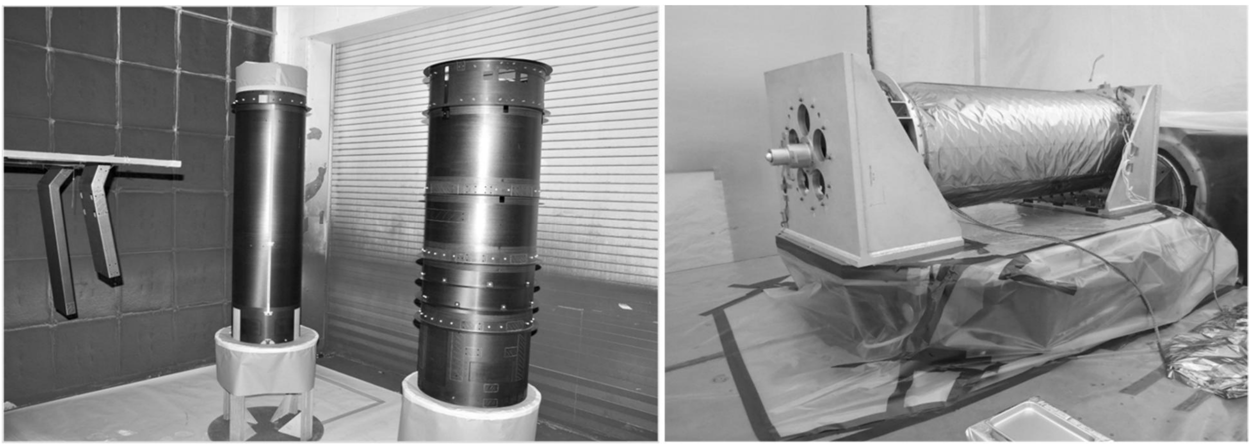

Figure 9: DTA inner and outer tubes (left) and DTA mechanism vibration testing (right)

6. OTE Electronics

The electronics in the OTE are comprised of the Actuator Drive Unit (ADU), which is housed in the Spacecraft, and the cryogenic boxes, consisting of the Cryogenic Junction Box (CJB) and 21 Cryogenic Multiplexer Units (CMUs). These electronics boxes, in conjunction with the Spacecraft electronics) control the motions of the actuators on each of the 18 PMSAs and the SMA, the deployment mechanisms (including release devices, deployment motors, and latching motors), and reads the telemetry from all of the mechanisms plus thermometry on the OTE. Figure 10 depicts the OTE electronics, all of which have completed acceptance testing and been delivered.

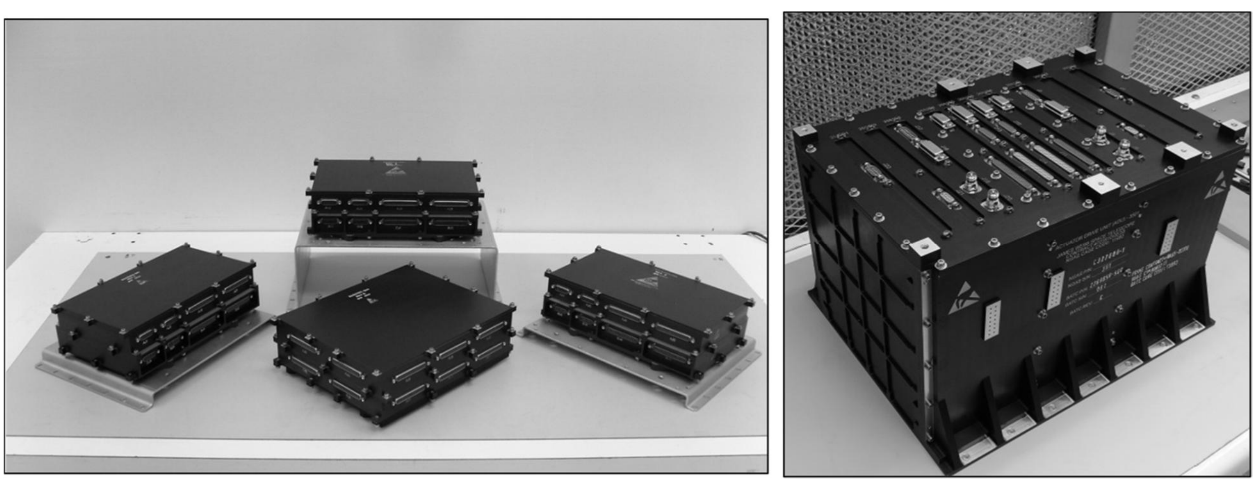

Figure 10: 3 of 21 flight CMU boxes with flight CJB (left) and flight ADU (right)

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7. Thermal Management System

The Thermal Management System (TMS) is comprised of a plethora of thermal control and stray light control hardware elements across the OTE. Because JWST is an infrared telescope operating between about 0.7 to 29 microns in wavelength, the functions of thermal control and stray light control are overlapping. Foremost in thermal rejection are the Fixed ISIM Radiators (FIRs) and the Aft Deployable ISIM Radiator (ADIR) which take residual heat dissipated from the electronics and mechanisms in the Science Instruments and radiates it to cold space. Both sets of radiators are depicted in Figure 2. The remaining TMS components consist of thermal and stray light baffles that are either fixed or deployed, plus thermal closeout Single Layer Insulation (SLI) and Multi-Layer Insulation (MLI). Figure 11 contains the various baffles used to aid in thermal and stray light control on the OTE. The frill is a stray light baffle that blocks light from behind the Primary Mirror from reaching the Secondary Mirror and entering the optical path. The Batwings serve as heat rejection, preventing thermal radiation from the warm region above the Spacecraft from reaching the ISIM enclosure. The Bib, along with the diagonal shields, serves to block thermal radiation from that same region, preventing it from reaching the SMA and scattering into the optical train. The ISIM Floor Shield (IFS), along with multilayer insulation and the diagonal shields, prevents thermal radiation from that same region from radiating directly to the ISIM from underneath. All of the TMS components have successfully completed their Critical Design Reviews and are in various states of manufacture.

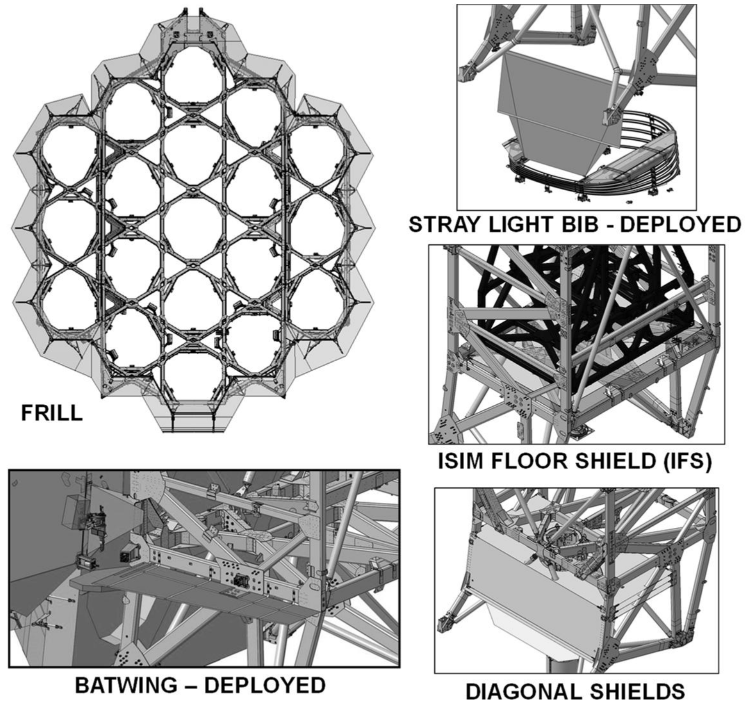

Figure 11: Components of the Thermal Management System

8. OTE Integration and Test

The OTE put together in two primary locations. The OTE Structure, without the optics and most of the TMS, is assembled in Redondo Beach, California. The first step is to install and align the wings and their deployment and latching mechanisms onto the PMBSS. The next step is to install and align the SMSS, and then the DTA. Complete electrical and deployment tests are performed, along with a modal survey of the OTE structure. Once the OTE structure is assembled, it is transported to Goddard Space Flight Center (GSFC) in Greenbelt, Maryland for optical integration in the Ambient Optical Assembly Stand (AOAS), depicted in Figure 12. Here, the 18 PMSAs, SMA, and AOS are installed and aligned.

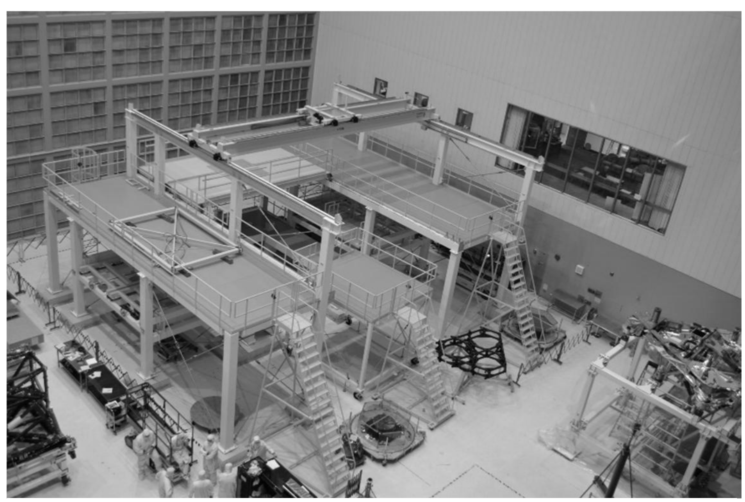

Figure 12: Completed Ambient Optical Assembly Stand

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Figure 13: Pathfinder SMSS installation and alignment

Once the optics are installed and aligned, the OTE is considered complete, even though some of its hardware has not been installed. The next level of integration consists of mating the ISIM with the OTE, after which all of the remaining OTE components, notably the radiators, can be installed.

A key tenet of the OTE integration and test program is to practice the integration and test steps as much as practical prior to performing them on the flight hardware. The OTE Pathfinder was created for this very purpose and is discussed in a separate paper in these proceedings. Using the same composite structure concept as is used for the PMBSS, the Pathfinder Backplane was built prior to the flight and served to aid in manufacturing and assembly operations. The Pathfinder SMSS, shown in Figure 8, served to practice, and refine, the process for assembling the large, lightweight composite structures with the precision deployment mechanisms. The Pathfinder SMSS has been installed and aligned to the Pathfinder Backplane, as depicted in Figure 13. Deployment walkouts have occurred and actual powered deployment testing of the SMSS is occurring currently. This serves to check out the support equipment and procedures that will be used for flight assembly and testing.

Like the flight OTE structure, the Pathfinder OTE structure will be transported to GSFC for optical integration. There, two PMSAs (the Engineering Development Unit (EDU) and another spare PMSA) and the EDU SMA will be installed and aligned. This will serve to practice the installation and alignment procedures and equipment that will be used for installing and aligning the flight optics into the OTE.

Because of the criticality of the installation and alignment of the PMSAs, demonstration runs have been performed of the installation process already using the EDU PMSA and the Backplane Stability Test Article (BSTA), as depicted in Figure 14. The BSTA is an exact subset of the PMBSS that holds up to 3 PMSAs. It can be seen in the lower portion of the image. The robotic arm that is used to align and hold the PMSAs can be seen in the upper portion of the image, along with the EDU PMSA. This demonstration served to check out the installation and alignment process for the PMSAs, along with the equipment that will be

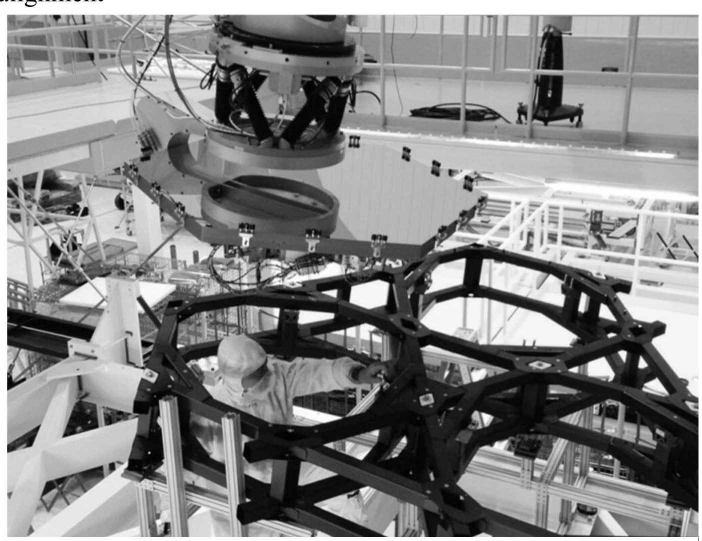

Figure 14: EDU demonstration with BSTA

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used to perform those operations on the flight OTE. Performing these operations again on the Pathfinder will ensure they go very smoothly once the flight OTE undergoes optical integration, starting in June of 2015.

CONCLUSION

The Optical Telescope Element has progressed significantly over the past several years. The design has been stable and hardware production has been continuing successfully. The majority of the effort to go is in integration and testing, as most of the flight hardware components have either completed, or are near completion of, fabrication. The OTE Pathfinder Structure has been completely assembled and will shortly be shipped to GSFC for optics integration. The flight OTE structure integration will start in July of this year, with optics integration starting in June of 2015.

ACKNOWLEDGEMENTS

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[1] Atkinson, C. B. , “Status of the JWST Optical Telescope Element”, p. 84422E-1 - 84422E-8, 8442-84, SPIE Proceedings, Amsterdam, July 2012

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